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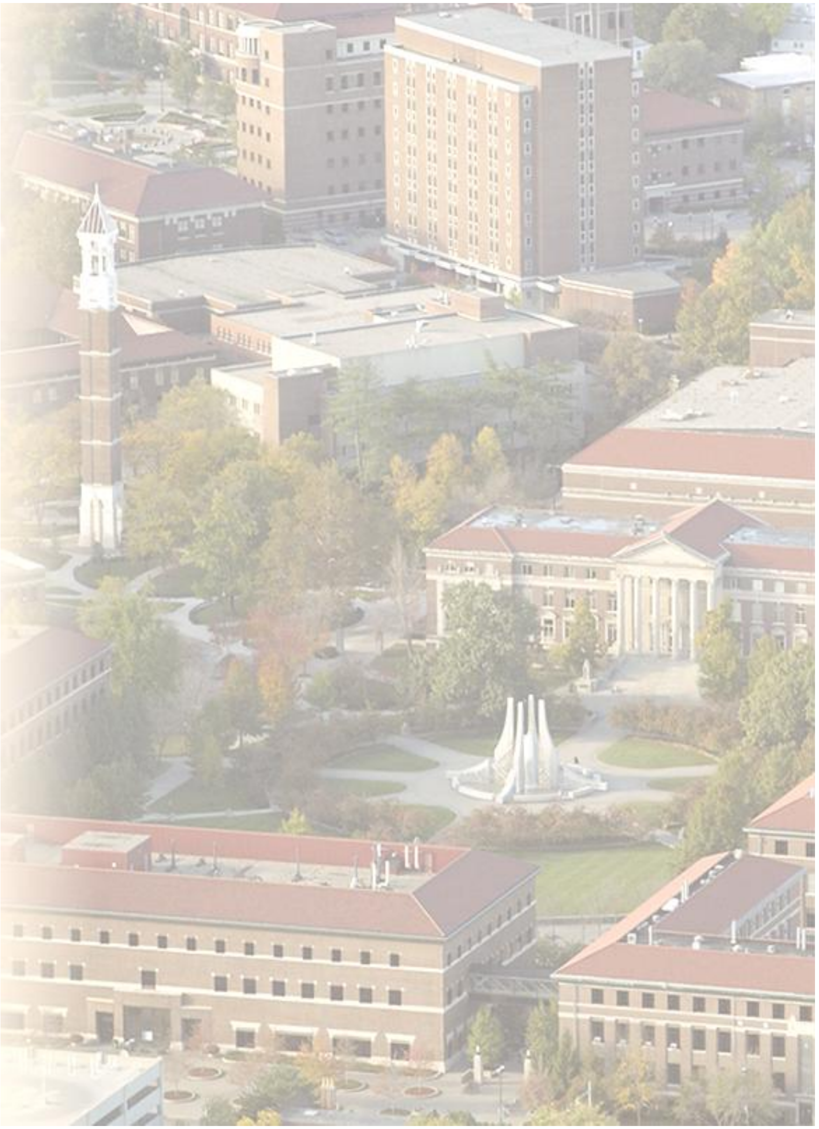
Capability and Development Risk Management in System-of-Systems Architectures: A Portfolio Approach to Decision-Ma

Muharrem Mane

Capability and Development Risk Management in System-of-Systems Architectures: A Portfolio Approach to Decision Making



NPS Acquisition Research Symposium
16-MAY -2012

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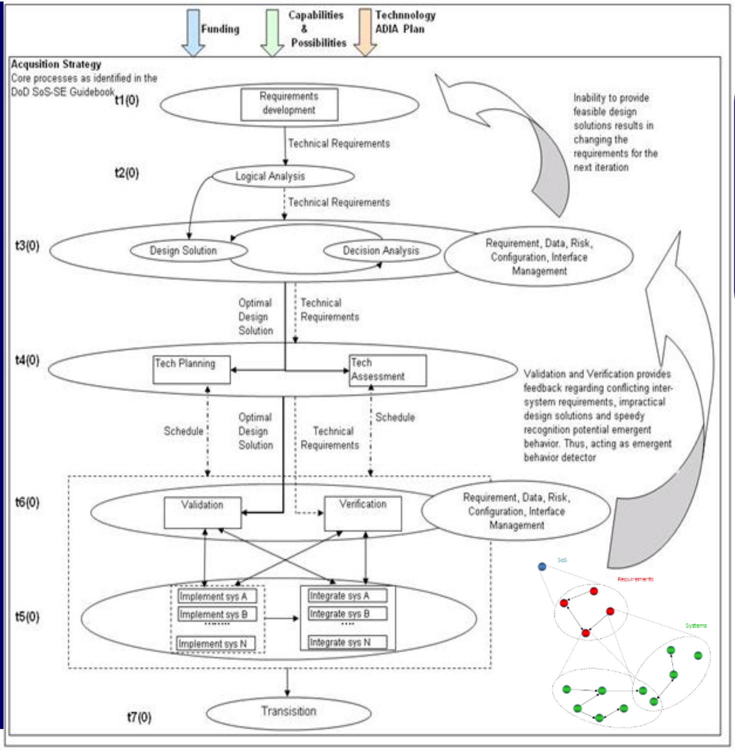
and System-of Systems Laboratory
Purdue University

Presentation Outline

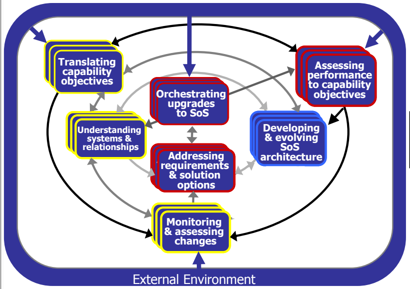
- The Big Picture
- SoS Architecting and Acquisition: Wave Model context
- An Investment Portfolio Approach
  - Mean Variance Approach
  - Mean-Variance: A Robust Version
- Concept Problem: Simple Littoral Combat Ship (LCS)
  - Robust Portfolio application
  - Multiple risk measures
- Future Work

The Big Picture ….

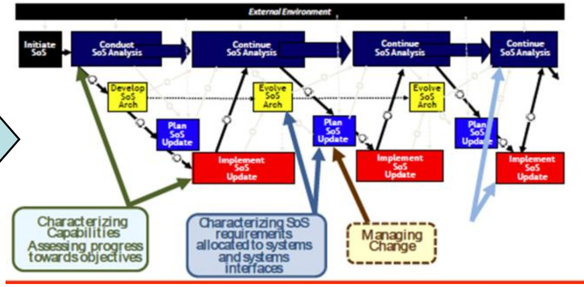
DoD SoSE Guidebook

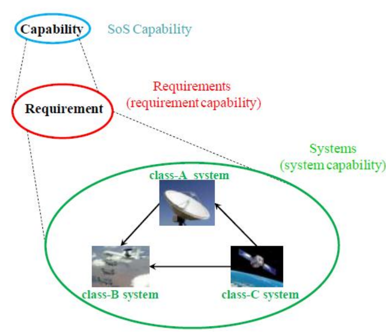


Trapeze

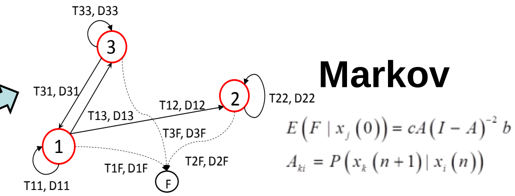


Wave Model

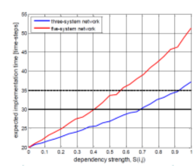


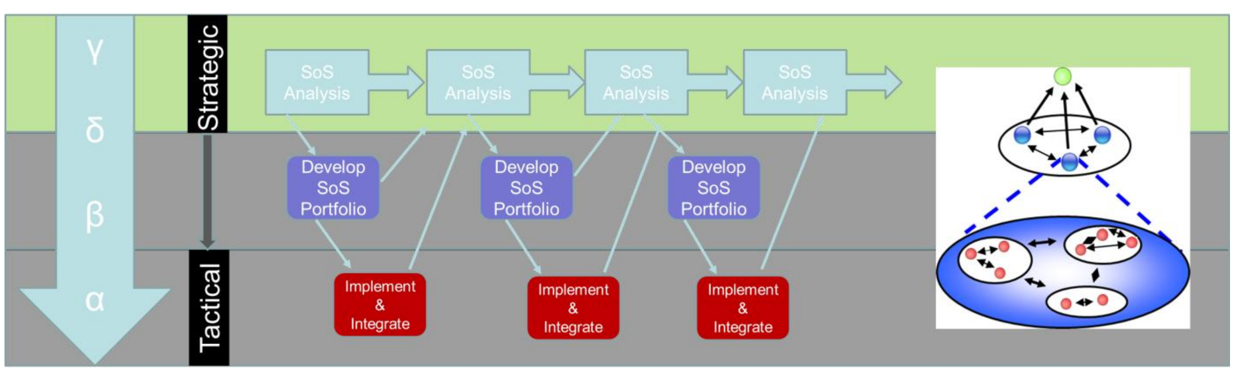


Markov



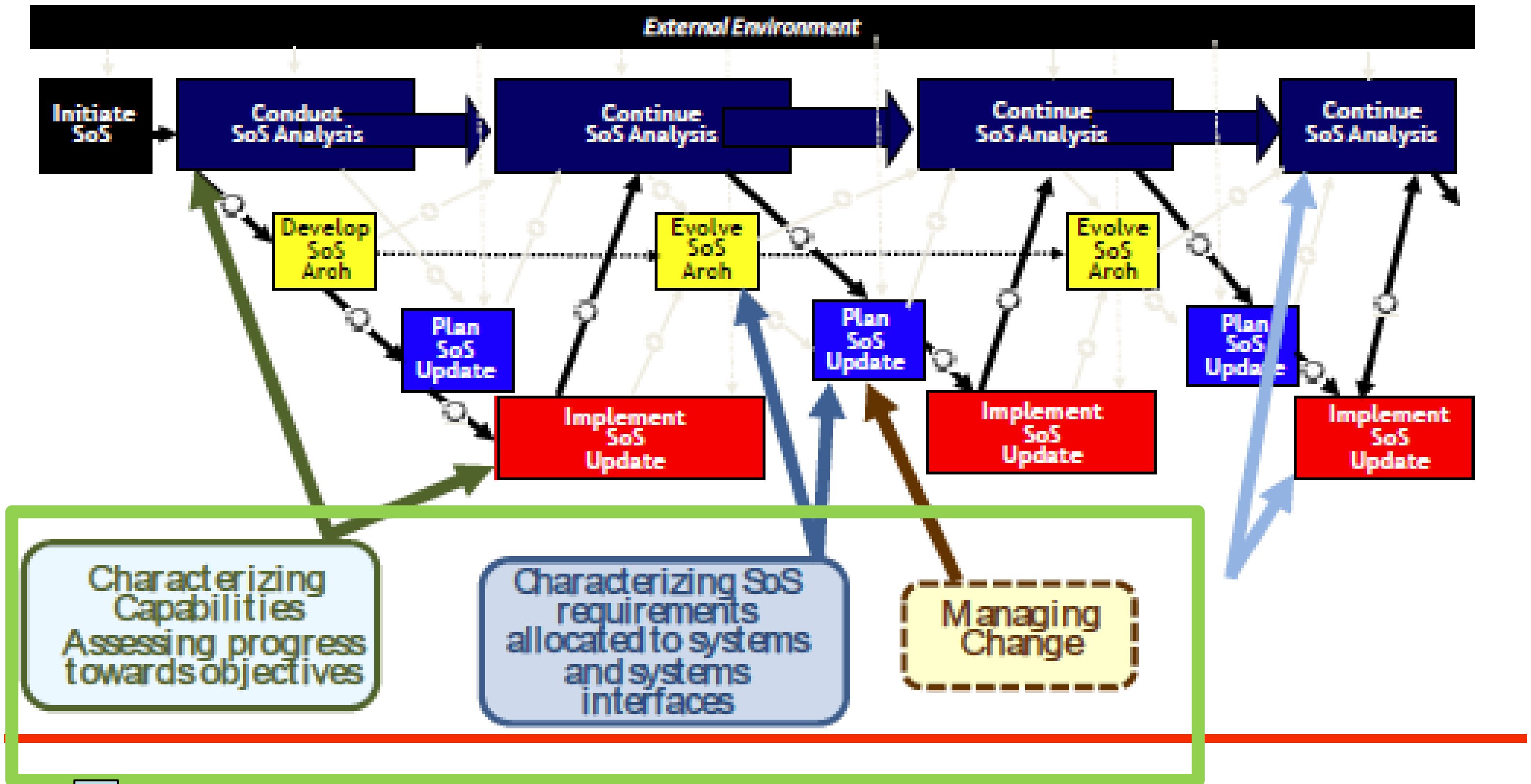
CEM





Methods	Nature	Inputs
CEM	Discrete Event Simulation	Probabilities, Connectivities
Markov	Probabilistic Graphical	Probabilities, Connectivities
Bayesian Network (BN)	Probabilistic Graphical	Conditional Distribution Connectivity
Portfolio Approach	Decision/Analysis based	Capabilities, Requirements, Connection rules

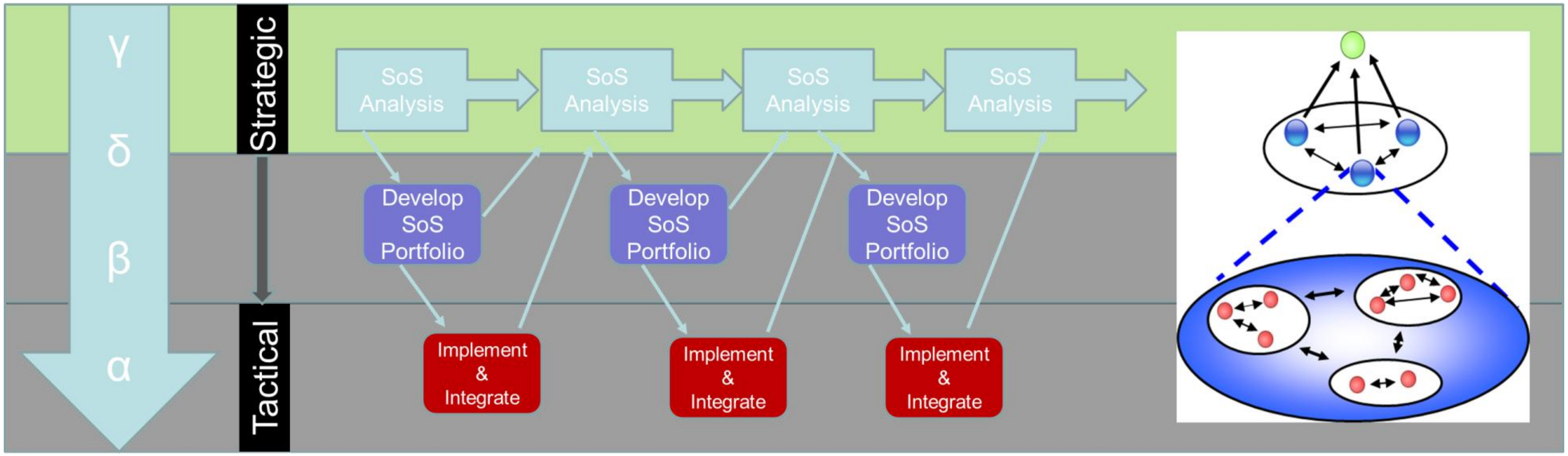
Wave Model*: SoS Architecture Development



How do we support these actions for SoS acquisitions?

*adapted from Dahmann et. al, "Integrating Systems Engineering and Test & Evaluation in System of Systems Development" IEEE Vancouver, 2011

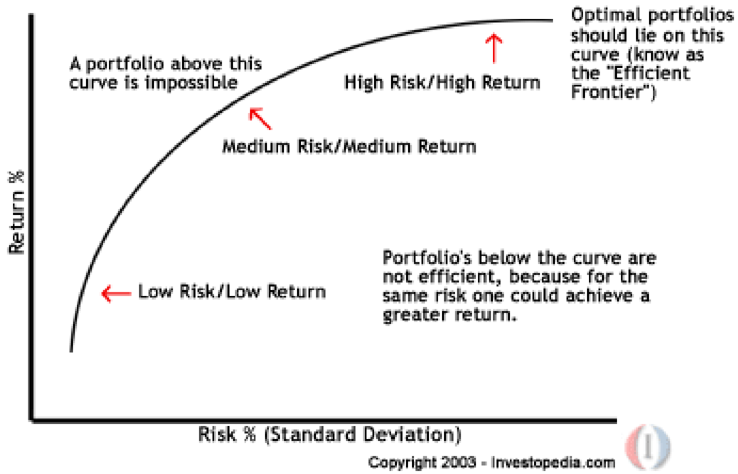
Wave Model: Acquisition and Architecture

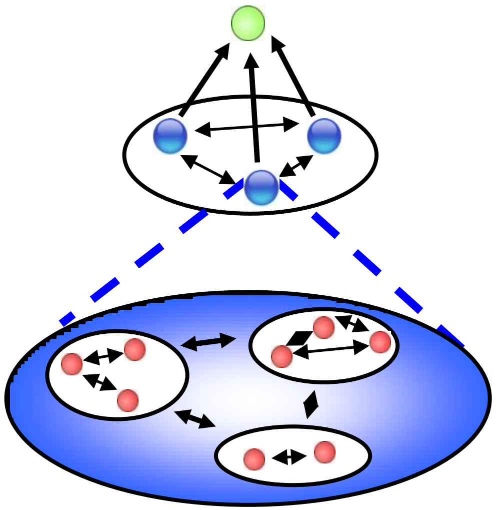


- How to leverage acquiring capabilities against associated risk?
    - Evolving requirements, Open Architectures (OA)
- What about system interdependencies?
- What about acquisition uncertainty considerations?
    - SRL, TRL, operational/developmental characteristics

A Portfolio Approach: Background

- Classical **Mean-Variance optimization** among techniques adopted by financial engineering and operations research.
- Balance **expected profit (performance) against risk (variance)** in investments
- Generates efficiency frontier of optimal portfolios given investor risk averseness
- Extends current frameworks (Housel, Mun, et.al)
- Systems (nodes) can be modeled as potential investment assets→ how do we invest?





Nodes = systems

Mean-Variance Portfolio Approach

Objective

Maximize Performance Index

Capability | Risk | Cost

$$\max\left(\sum_q\left(\frac{S_{qc}-R_c}{R_c}\cdot w\cdot X_q^B\right)-\lambda\left(X_q^F\right)^T\Sigma_{ij}X_q^F-\sum_q\left(C_qX_q^B\right)\right)$$

Constraints

Portfolio Fraction

$$X_q^F=\frac{X_q^BC_q}{\text{Budget}}\ \text{(Portfolio Fractions)}$$

Portfolio Total Budget

$$\sum_q C_qX_q^B+\varepsilon=\text{Budget}\ \text{(Budget Constraint)}$$

Requirements Satisfaction

$$\sum_q S_{qC}X_q^B\geq\sum_q S_{qR}X_q^B\ \text{(Satisfy All System Requirements)}$$

Selection Rules (Compatibility)

$$X_1^B+X_1^B+X_1^B=1\ \text{(ASW System Compatibility)}$$

$$X_4^B+X_5^B=1\ \text{(MCM System Compatibility)}$$

$$X_6^B+X_7^B=1\ \text{(SUW System Compatibility)}$$

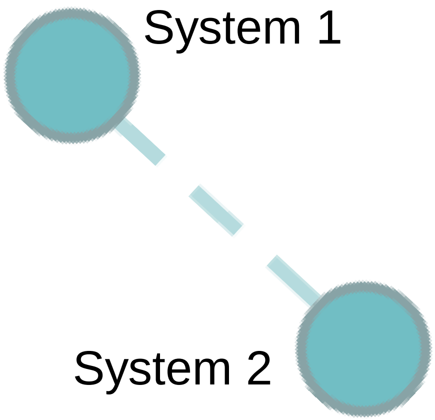
$$X_8^B+X_9^B+X_{10}^B=1\ \text{(Package System Compatibility)}$$

Uncertainty in Covariance (Interdependencies)

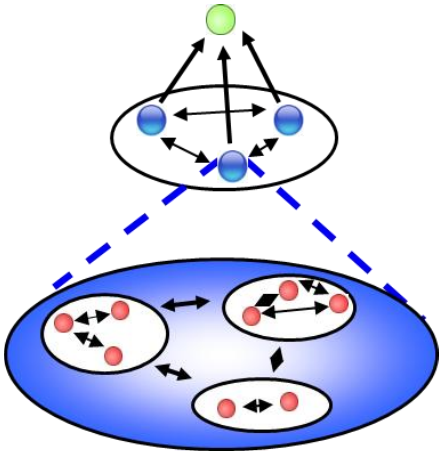
$$\Sigma_{ij}^L\leq\Sigma\leq\Sigma_{ij}^U$$

Portfolio Uncertainty

- Sources of uncertainty
  - **System Capability**: Actual performance of system individually and as a whole SoS entity
  - **System Interdependence**: Interdependency variances/covariances?



- Addressing uncertainty
  - Operations Research/Financial Engineering Methods to address uncertainty measures
  - Introduce uncertainty in interdependencies and individual asset performances
  - Introduce SoS connectivity in portfolio space



Mean-Variance Portfolio: Robust Approach

Objective

Maximize Performance Index

$$\max\left(\underbrace{\sum_q\left(\frac{S_{qc}-R_c}{R_c}\cdot w\cdot X_q^B\right)}_{\text{Capability}}-\underbrace{\lambda\left\{\left\langle\overline{\Lambda}\overline{\Sigma}\right\rangle-\left\langle\underline{\Lambda}\underline{\Sigma}\right\rangle\right\}}_{\text{Risk}}-\underbrace{\sum_q\left(C_qX_q^B\right)}_{\text{Cost}}\right)$$

Constraints

Portfolio Fraction

$$X_q^F=\frac{X_q^BC_q}{\text{Budget}}\text{(Portfolio Fractions)}$$

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Reformulate as SDP (Tutuncu & Koenig 2004)

$$\begin{bmatrix}\overline{\Lambda}-\underline{\Lambda} & X_q^F\\ X_q^{F}{}' & 1\end{bmatrix}\succeq 0\ \text{(Linear Matrix Inequality)}$$

$$X_q^B\in\{0,1\}\text{(binary)}$$

Robust Portfolio Case Study: Simple LCS Portfolio

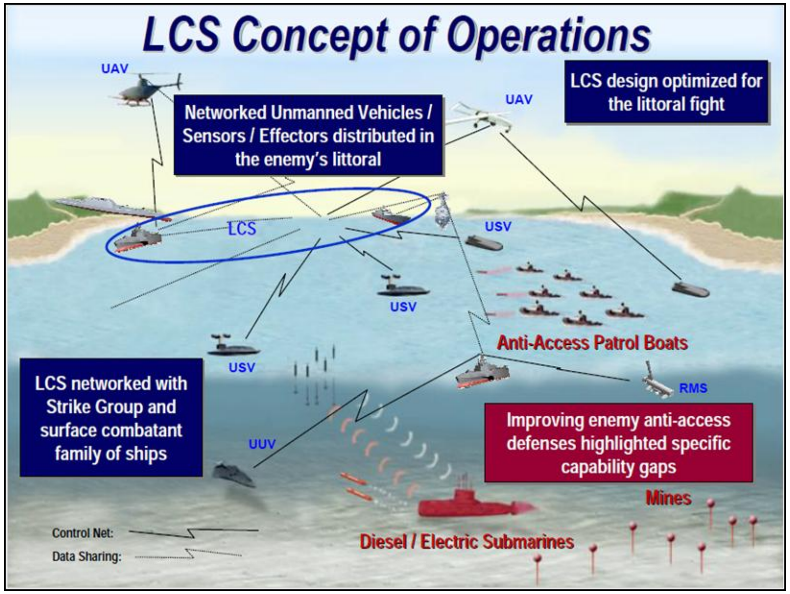


Table 2: System interdependency and development risk (covariance)

	able Depth	ti Fcn Tow	tweight tow	MCS II	DS (MH-60)	S Missiles	fin Missiles	age System 1	age System 2	age System 3
Package System 2	0	0.1	0	0.2	0	0.1	0	0	0.3	0
Package System 3	0	0	0.2	0	0.3	0	0	0	0	0.2

Diagonal : System Variance

Off Diagonal : System Interdependency

Table 1: Individual system information

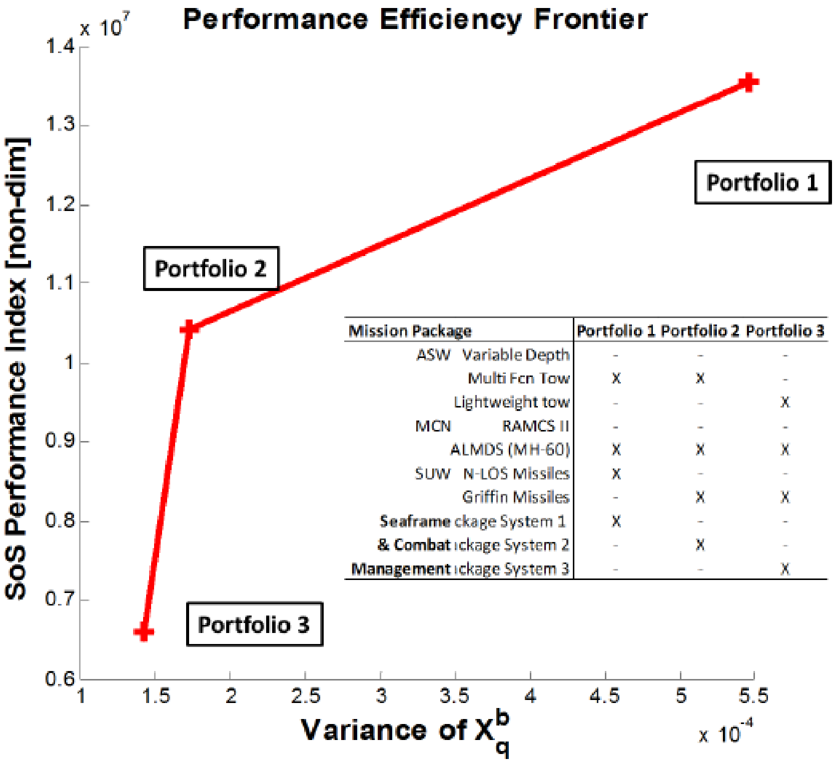
		System Capabilities					System Req.		Develop. Time	Acq. Cost
		Weapon Strike Range	Threat Detection Range	Anti Mine Detection Speed	Comm. Capacity	Air/Sea State Capacity	Air/Sea State	Comm.	(Years)	($)
Package										
ASW	Variable Depth	0	50	0	0	0	0	250	3	3000000
	Multi Fcn Tow	0	40	0	0	0	0	150	2	2000000
	Lightweight tow	0	30	0	0	0	0	100	4	4000000
MCN	RAMCS II	0	0	40	0	0	3	200	1	1000000
	ALMDS (MH-60)	0	0	30	0	0	4	100	2	2000000
SUW	N-LOS Missiles	25	0	0	0	0	0	200	3	3000000
	Griffin Missiles	3	0	0	0	0	0	100	4	4000000
Seaframe	Package System 1	0	0	0	400	4	0	0	3	3000000
& Combat	Package System 2	0	0	0	300	4	0	0	4	4000000
Management	Package System 3	0	0	0	250	3	0	0	5	5000000

Capability

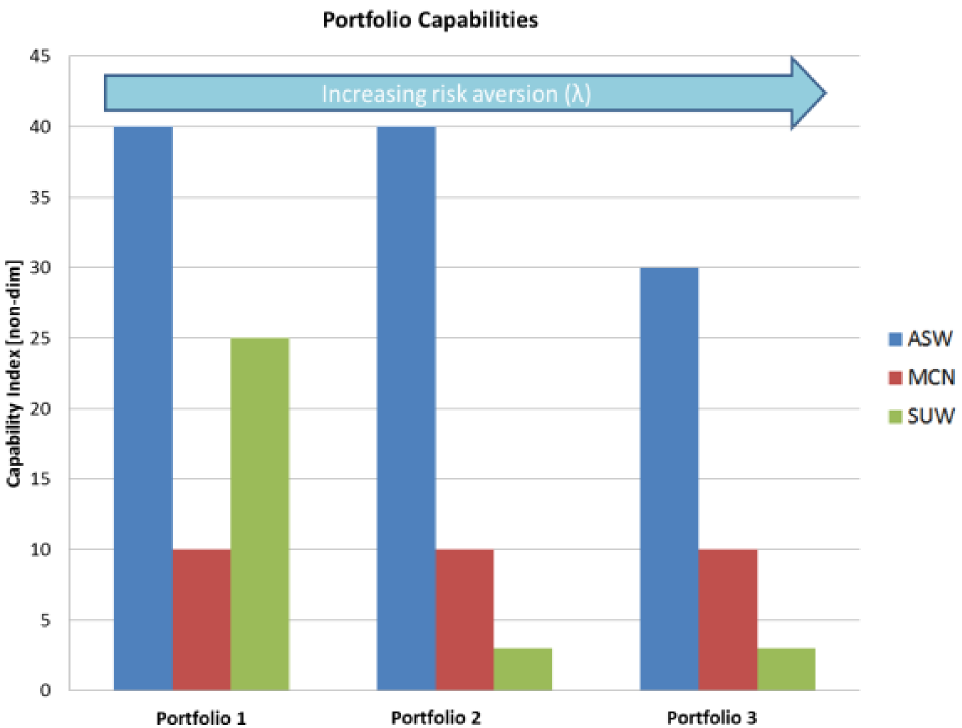
Requirement

Image from: Presentation slides by RDML Vic Guillory of OPNAV at Mine Warfare Association Conference (titled "Littoral Combat Ship", 08-May-07)

Robust Portfolio Case Study: Simple LCS Portfolio

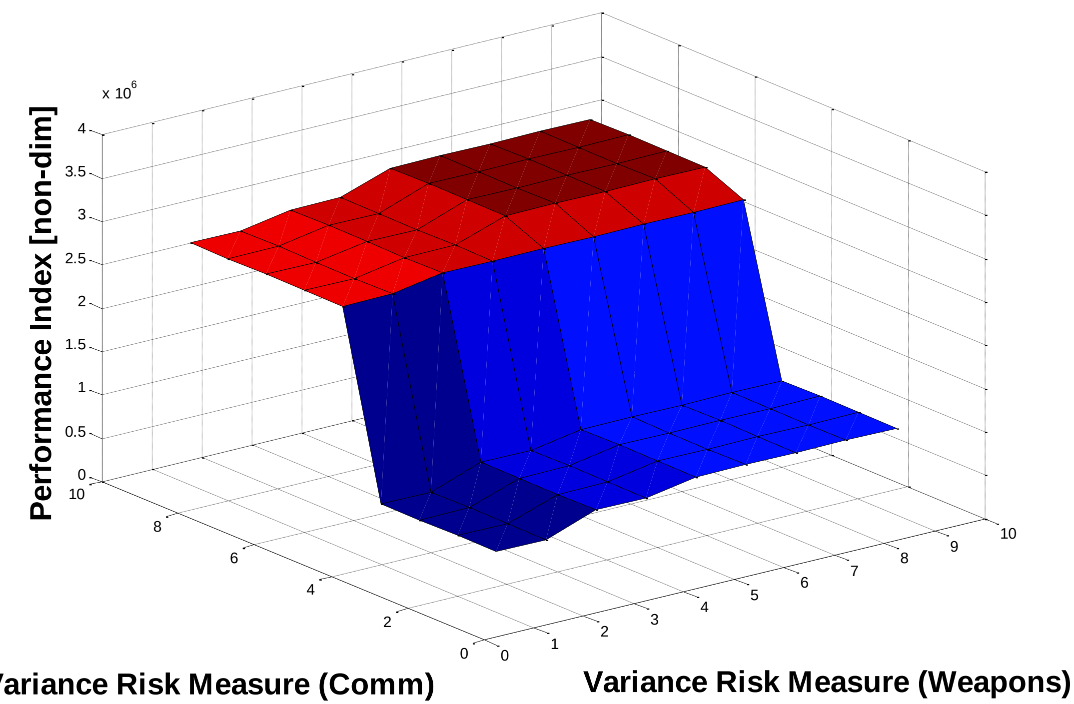


Mission Package		Portfolio 1	Portfolio 2	Portfolio 3
ASW	Variable Depth	-	-	-
	Multi Fcn Tow	X	X	-
	Lightweight tow	-	-	X
MCN	RAMCS II	-	-	-
	ALMDS (MH-60)	X	X	X
SUW	N-LOS Missiles	X	-	-
	Griffin Missiles	-	X	X
Seaframe	ckage System 1	X	-	-
& Combat	ıckage System 2	-	X	-
Management	ıckage System 3	-	-	X



Portfolio Approach: LCS Multiple Risk Measures

- Layered measure of risk (e.g. weapons vs. communications layer).
- Separate covariance for each measure of risk



Comm. Variance (Risk) Constraint	→	$\sqrt{(X_i^B)^T \Sigma_{ij}^{comm} X_i^B} \le \sigma_{comm}$
Weapon Variance (Risk) Constraint	→	$\sqrt{(X_i^B)^T \Sigma_{ij}^{weapons} X_i^B} \le \sigma_{weapon}$

Summary/Conclusion

- RMVO promising framework to leverage SoS performance against risk
- Considers uncertainty and system interdependencies explicitly in portfolio construction
- Needs more realistic data (performance, interdependencies) for real world application and verification

Portfolio Approach: Future Work

- Extend to multi-period considerations
  - How do I make investment decisions in changing environments?
  - Can I hedge my bets for future anticipations?
    - (e.g. price of steel in LCS program?)
  - Do my decisions now allow me to <u>learn</u> for the future?
    - Similar technologies, frameworks ➔ knowledge space?

$$\max \underbrace{\left(\sum_q \left(\frac{S_{qc} - R_c}{R_c} \cdot w \cdot X_q^B \right) - \lambda \left(X_q^F \right)^T \Sigma_{ij} X_q^F - \sum_q \left(C_q X_q^B \right) \right)}_{A}{}_t + E\left(A_{t+1} \mid w_{t+1}, \Sigma_{t+1}, \lambda_{t+1} \right)$$

Capability vs. Risk now

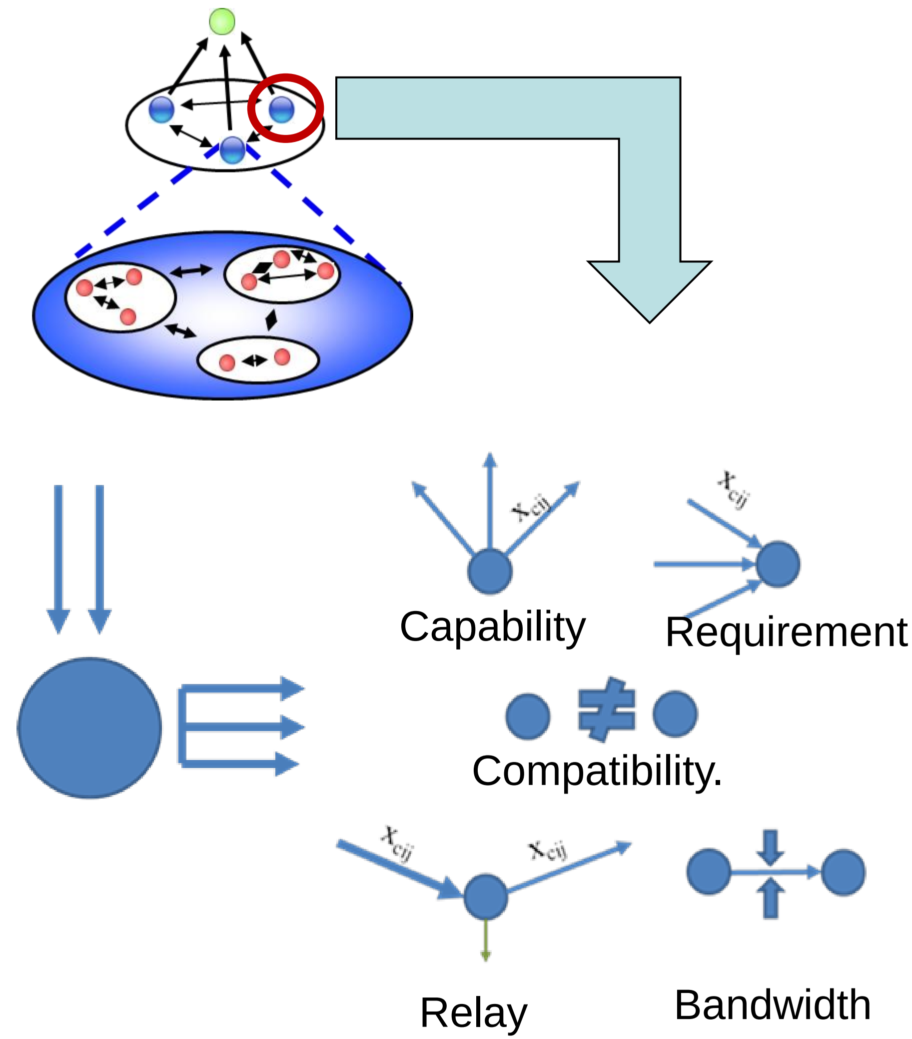
Effect on Capability Later

- Application to more realistic world SoS portfolio problems

Extra/Backup Slides

Portfolio Approach: SoS Modelling Additions

- Model individual system as 'nodes'
  - Functional & Physical representation
- Rules for node connectivity (this is currently not addressed elsewhere, e.g., RT-18)
  - Compatibility between nodes
  - Bandwidth of linkages
  - Supply (Capability)
  - Demand (Requirements)
  - Relay capability



Extension to SoS Interconnectivities

Maximize Capability Performance Index

$$\max\left(\frac{\sum_i S_{ic}\cdot w\cdot X_i^B - R_c}{R_c}\right)$$

s.t.

Sufficient Capabilities Supplied

$$\sum_i X_{cij} \geq X_j^B S_{rj}$$

Individual System Requirements met

$$\sum_i X_{cij} \geq X_j^B S_{rj}$$

Connectivity Rules Obeyed (Big-M formulation)

$$X_1 + \cdots + X_n = 0$$

$$\sum_c X_{cij} - X_{ij} M \leq 0$$

$$M \sum_c X_{cij} - X_{ij} \geq 0$$

$$\sum_i X_{cij} - \sum_j X_{cij} - X_j^B S_{rj} = 0$$

Risk Tolerance (per measure of risk)

$$\sqrt{\left(X_i^B\right)^T \Sigma_{ij} X_i^B} \leq \sigma_{critical}$$

$$X_{cij} \leq \mathrm{Limit}_{cij}$$

$$X_{cij} = 0 \quad c \in \text{capability}$$

$$\Sigma_{ij}^L \leq \Sigma_{ij} \leq \Sigma_{ij}^U$$

$$X_{cij}, X_j^B \in \text{ binary } \{0,1\}$$